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A THREE-AXIS PROBE FOR 60 Hz MAGNETIC FIELDS

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A three-axis magnetic field probe has been developed for the Electric and Magnetic Field Risk Assessment Program to trace 60 Hz magnetic fields to their sources. The probe can also be used as the sensor for a data logger.

INTRODUCTION

Development of a three-axis magnetic field probe has been undertaken as part of the Source Characterization project in the Electric and Magnetic Field Risk Assessment Program. Previously a commercially available single axis probe was used to detect magnetic fields and trace them to their source. Such a device is difficult to use because the pickup coil must be continuously rotated to align it with the local orientation of the field. A portable hand-held three-axis probe that measures the resultant field in real time is needed. This device must also filter out low frequency noise caused by the movement of the probe in the Earth's magnetic field.

Commercially available three-axis sensors were not suitable. One model does not provide a way of measuring the resultant field in real time, which makes tracing the magnetic fields difficult. Another requires a computer to find the resultant field, and is not suitable for portable use.

A portable three-axis magnetic field probe has been developed. This device has a lightweight probe head equipped with three orthogonal pickup coils to sense the field along all three axes. A battery operated unit processes the data from the probe head into a resultant vector and it filters the data to eliminate spurious results caused by movement in the Earth's magnetic field. Further, it will measure the true rms value of the field to provide the correct exposure assessment when harmonics are present.

OBJECTIVES

The design objectives to be met by the probe are as follows:

1) To provide a simple way of measuring polarized magnetic fields, from 60 Hz to 600 Hz, and to ignore ac fields outside of this frequency band.

2) To provide outputs for a data acquisition unit.

3) To be portable and to be sensitive to 1 IT full scale. It should also have range settings to allow the measurement of larger fields.

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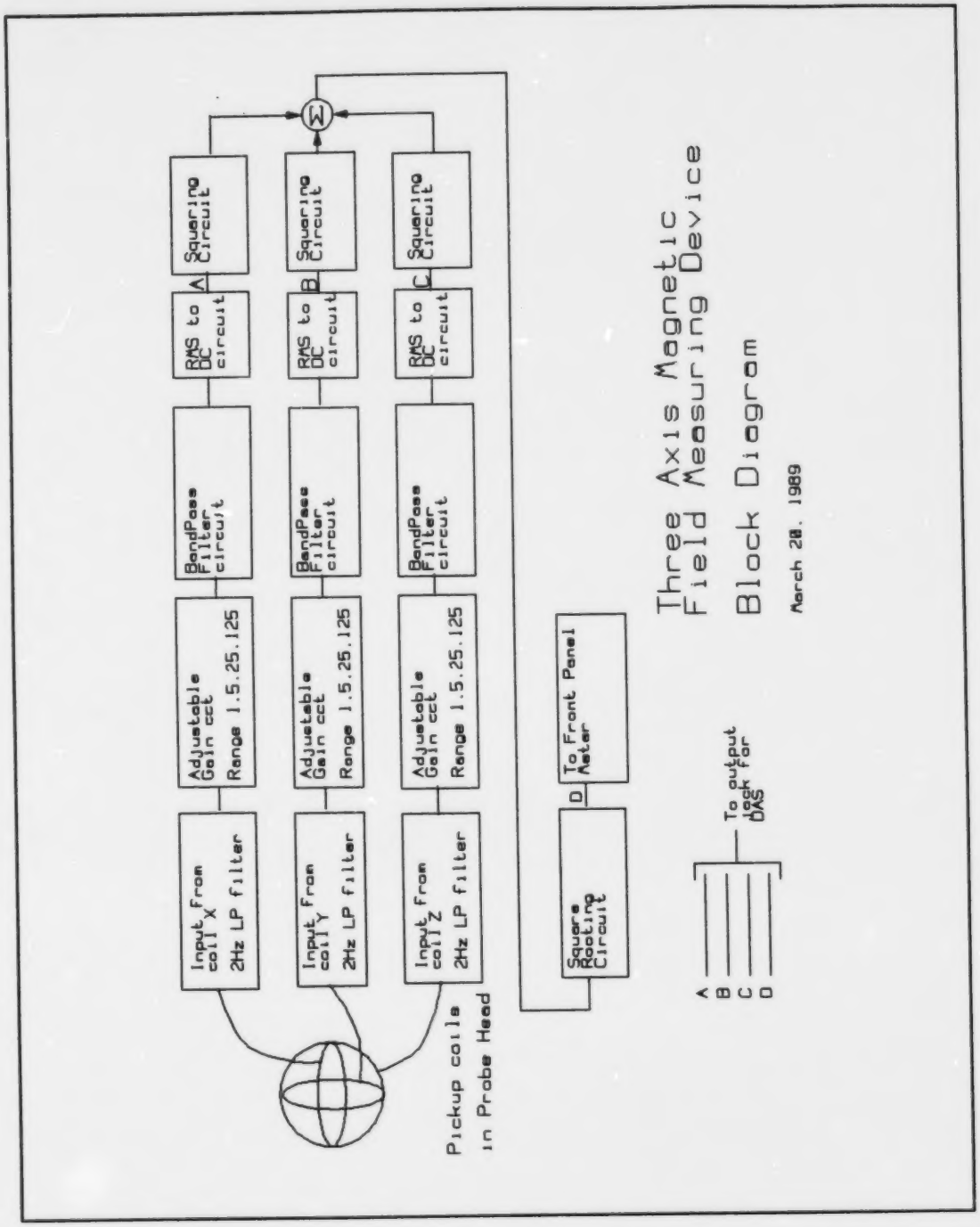

Figure 1 - Block Diagram of the Three Axis Probe

4) To operate on an internal battery or an external power source.

THEORY OF OPERATION

To measure a polarized magnetic field the following strategy was used/1/.

1) The magnetic field along each axis was measured and the frequencies outside the range of interest are filtered out.

2) The true rms values of the fields are found, using rms to dc converters.

3) The resulting signals are then summed vectorially.

The block diagram of the circuit is shown in Figure 1.

PERFORMANCE SPECIFICATIONS

To test the performance of the three-axis probe a Helmholtz coil with a known geometry was used to generate a spatially uniform field. This coil will provide 20.6 lT/Ampere. Since the Helmholtz coil produces a field in a single direction, the probe head was rotated to excite each of the three pickup coils individually.

The performance specifications of the probe will be divided into 2 sections. These are the amplification and filtering section and the vector addition section.

Amplification and Filtering

To measure the frequency response an HP35660A Signal Analyzer and a Yamaha PC5002M power amplifier were used to supply current to the Helmholtz coil, resulting in a field of 2lT at 60Hz. This field value was large enough that the background 60Hz fields would not significantly affect the results of the test. However, a small spike is seen in the magnitude response at 60Hz. Since the probe head is not iron-cored the response of the probe head will be proportional to the field being measured.

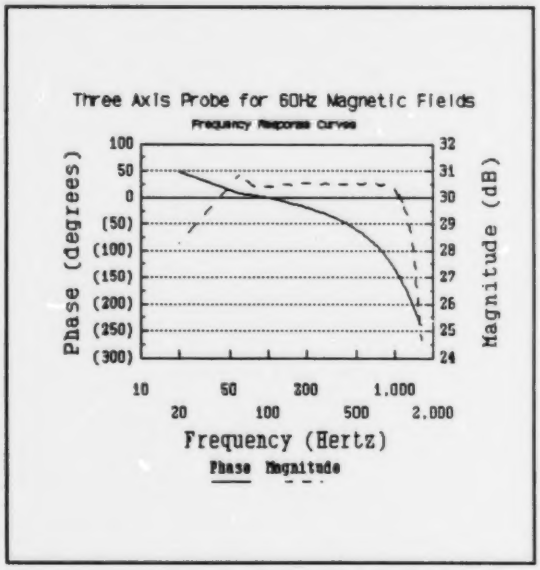

Figure 2 - Frequency Response

The conditioned signal was measured at the input of the rms to dc circuit and compared with the current exciting the Helmholtz coil. The magnitude and phase responses of the probe at this point are shown in Figure 2. The magnitude response shown is for Range 2 of the probe and is in dBV. Because the range switch selects different gains the other ranges have a similar frequency response except that they are shifted by a constant offset.

The waveform accuracy is shown in Figure 3. This figure compares a nonsinusoidal input current waveform to the Helmholtz coil with the field measurement from the probe. As expected from the frequency response curves the waveform is distorted relative to the input.

The operation of the rms to dc circuit was verified by comparing the output of the rms to dc circuit with the rms level computed by the Tektronix 2430A Oscilloscope for the same input waveform. The waveform used was the same as the one shown in Figure 3. The oscilloscope is an 8-bit device that is accurate to 2%.

A connector is provided to allow a data logger to be added to the circuit. This will allow the X_{rms} Y_{rms} and the Z_{rms} fields to be recorded over time. The output of the vector addition circuit is also available for use with a data logger, however due to the limited dynamic range of the vector addition circuit, approximately 10 dB, the resultant should be determined digitally.

Vector Addition

To determine the resultant field, the outputs of the rms to dc converters X, Y, and Z were squared and summed. The sum was fed to a square rooting circuit giving the total magnetic field as the resultant R:

$$R = (X^2 + Y^2 + Z^2)^{1/2}$$

The analog implementation of this method does limit the dynamic range of the resultant magnetic field, but this limitation is not significant when using the probe for finding current carrying conductors. This does not affect data logger output from the three individual coils since their output occurs before the vector addition circuit.

To quickly test the vector addition circuit the probe head can be placed in an unidirectional field and rotated. If the meter reading does not change the vector addition circuit is working properly.

The actual performance of the vector addition circuit is shown in Figure 4. This figure compares the theoretical deflection of the meter with the actual deflection of the meter for all 4 ranges of the probe. It shows that when fields are less than 25% of full scale the meter reading is not accurate. This is caused by the square rooting circuit needing a signal of 0.3V before it will start to operate. This is a limitation of using analog circuitry to perform the mathematical operations. This limitation could be eliminated by performing the squaring operations with a microprocessor.

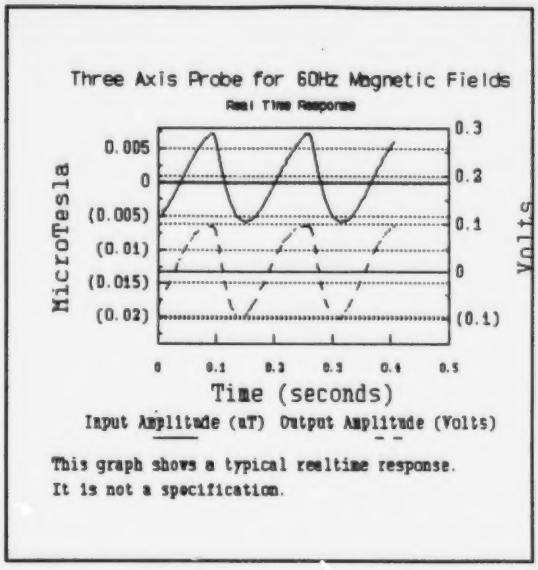

Figure 3 - Realtime Response of Probe

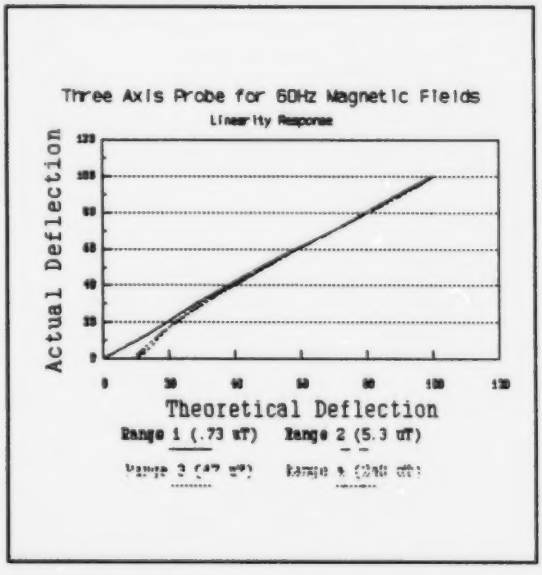

Figure 4 - A Comparison of Meter Reading versus Actual Field

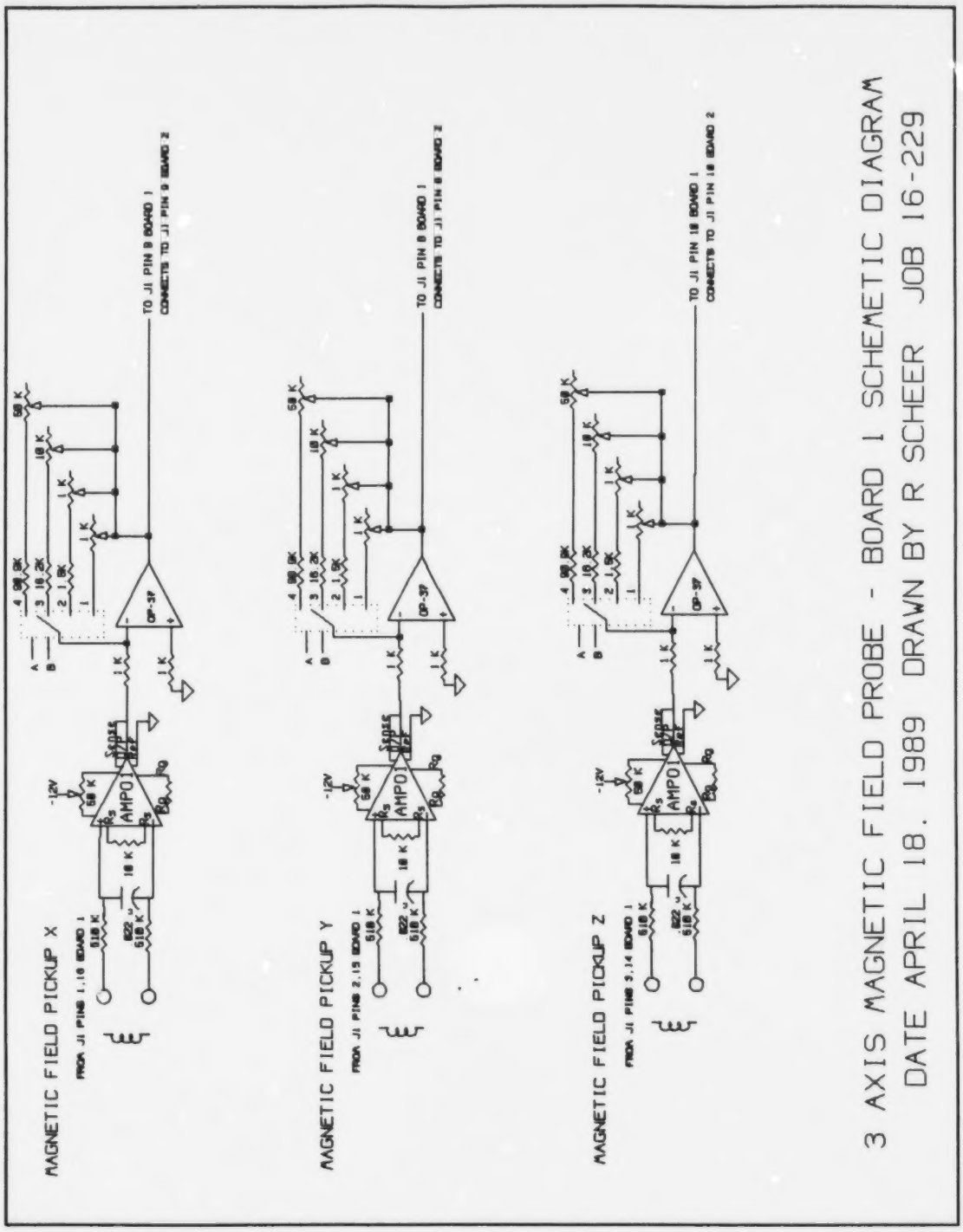
MAGNETIC FIELD PICKUP X
MAGNETIC FIELD PICKUP Y
MAGNETIC FIELD PICKUP Z
3 AXIS MAGNETIC FIELD PROBE - BOARD 1 SCHEMETIC DIAGRAM
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Figure 5 - Schematic Diagram of Board 1

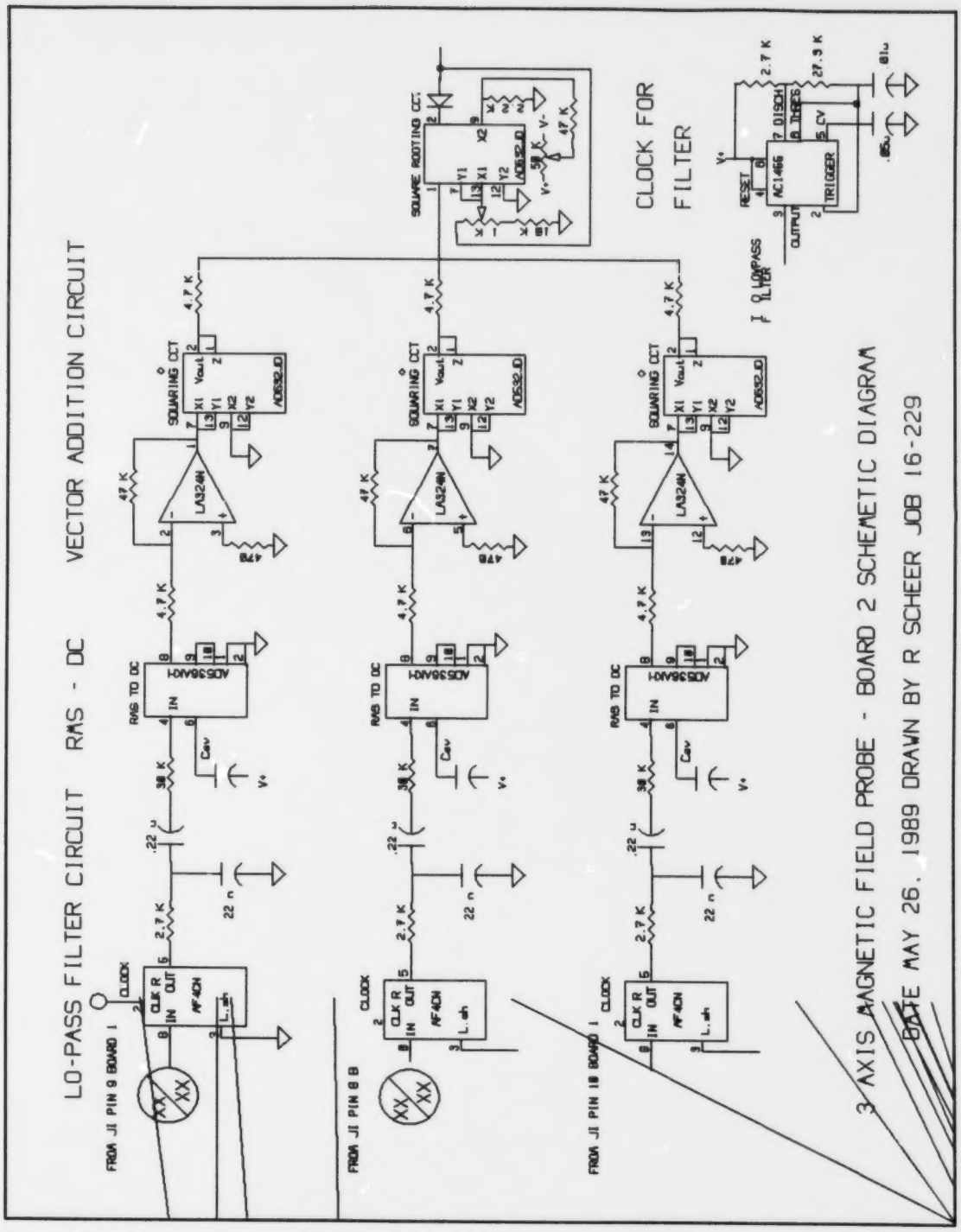

Figure 6 - Board 2 Schematic Diagram

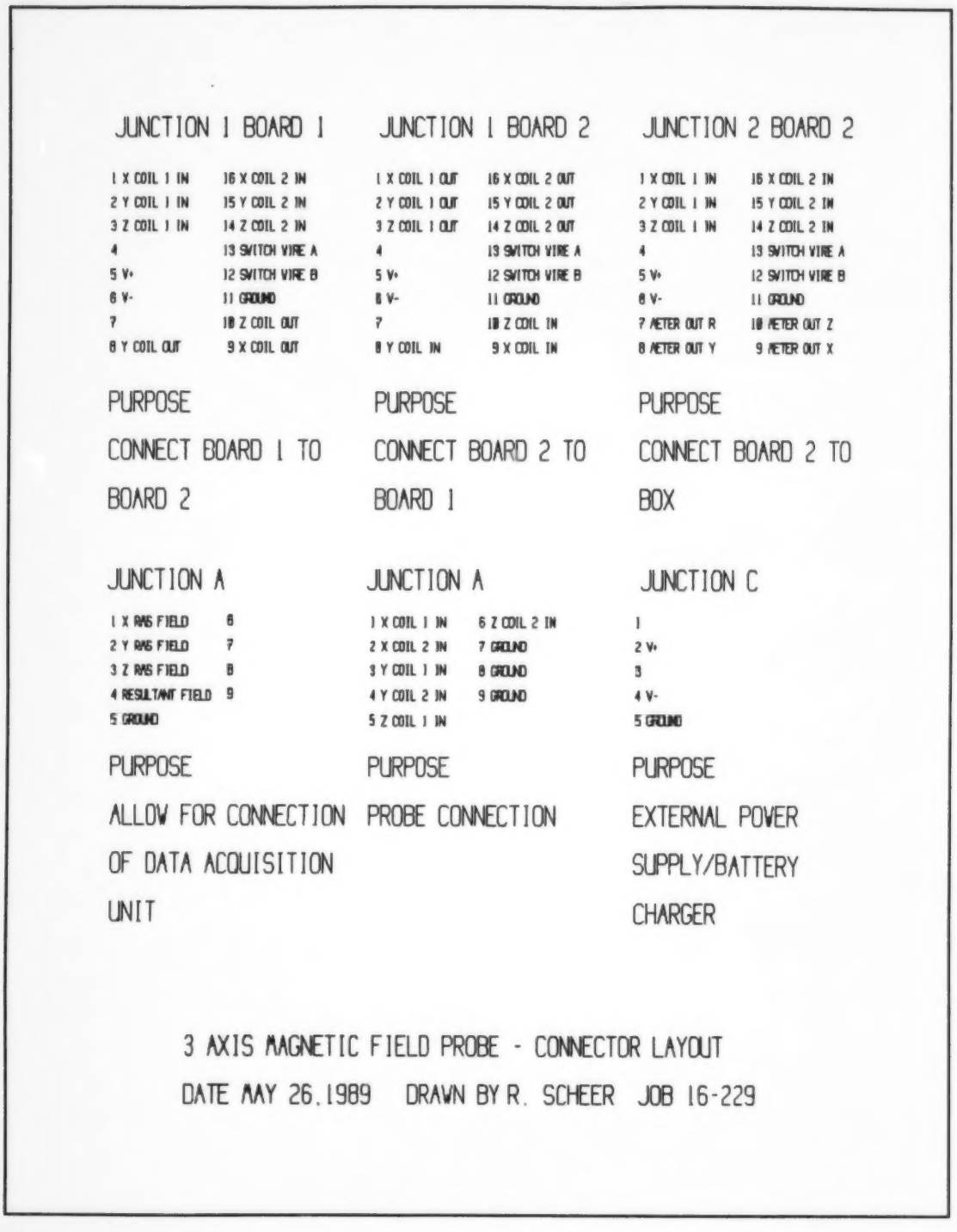

Figure 7 - Connector Pinouts

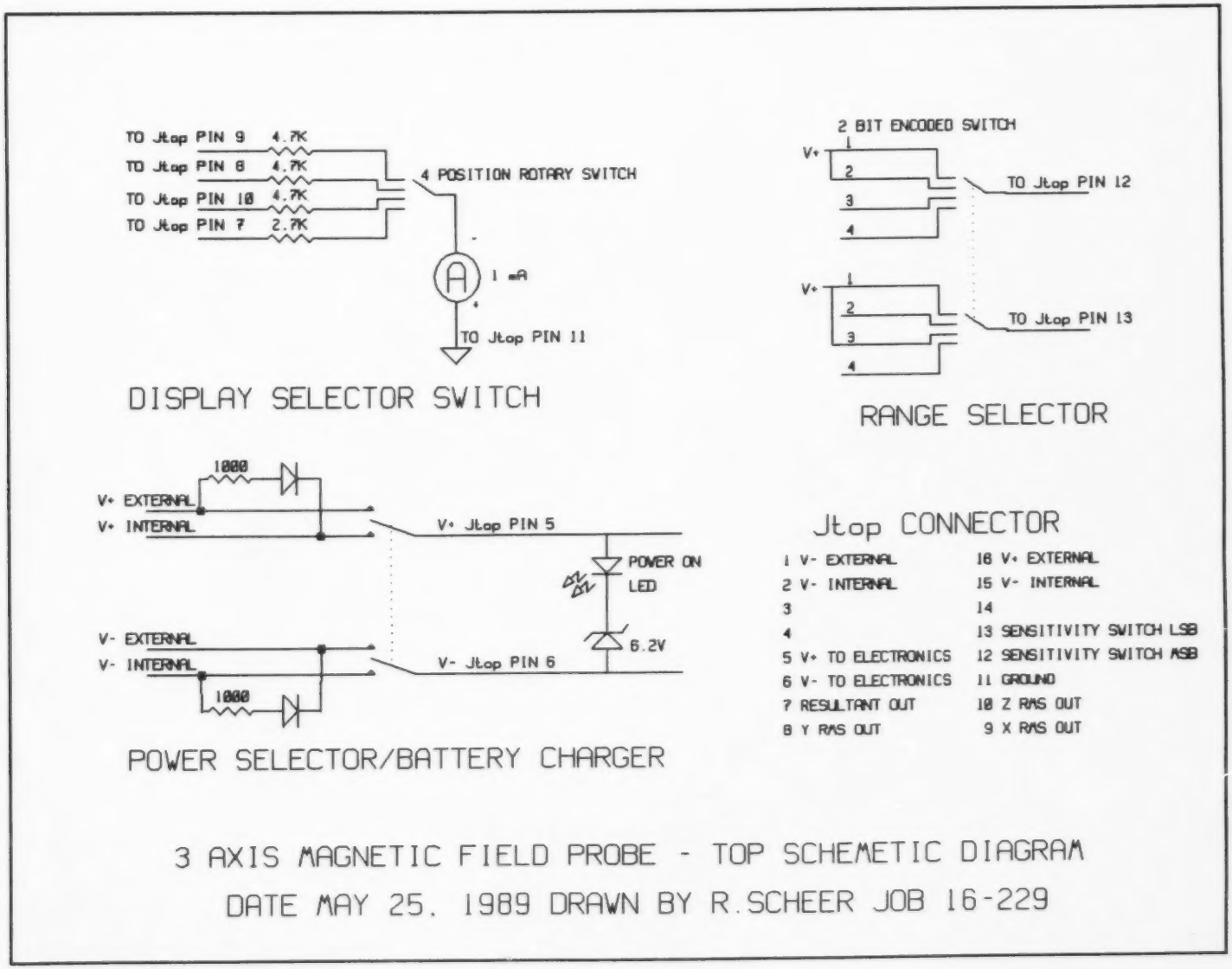

Figure 8 - Schematic Diagram of Processor Cover

CIRCUIT DESCRIPTION

The schematic diagrams of the three-axis sniffer are shown in Figures 5, 6, 7, and 8. The purpose of each part of the circuit will be described individually. Note: Power lines and bypass capacitors have not been shown in order to simplify the schematics. All bypass capacitors have a value of 1 lF.

Figure 5

This circuit provides the initial amplification and filtering of the signal from the probe head. The signal comes from the probe head into a single pole resistor capacitor filter. This filter has a cutoff frequency of 2 Hz and its purpose is to remove the frequency dependency of the pickup coils. The signal then goes into the AMP01 instrumentation amplifier which boosts the signal by a fixed 60 dB.

The next section of the circuit provides a programmable gain of 1, 5, 50, and 250 by changing the feedback resistance. The switch used is the Motorola MC14052BCP, which is controlled by the 2-bit encoded switch shown in Figure 8.

Figure 6

The signal from Board 1 is sent through a 4-pole switched capacitor filter, National Semiconductor (MF4CN-50). This eliminates any frequency above the range of interest from exciting the meter. The signal then goes through a bandpass network to remove any dc offset from the signal and to further limit any high frequency feedthrough.

The cutoff frequencies of the bandpass resistor capacitor network are 13 Hz and 2.6 KHz. This circuit provides the initial amplification and filtering for each of the three axes. The signal is then sent to the rms to dc converter (AD536AKH). The rms output is amplified by 20 dB to bring the signal into the proper range for the squaring circuit (AD532JD). The output of the squarer is sent to a summing circuit and then the square root of the summer is found and sent to the panel meter.

Figure 7

Figure 8 shows the pinouts for all the connectors in the processing box except for the connector for the top. For each connector the pin number and the signal on the pin are given. The connector names correspond with the names on the actual connectors.

Figure 8

This figure shows the schematic diagram for the top of the processing box. There are three functions performed on the schematic and they will be described individually.

Display Selector Switch

This selector selects what will be displayed on the meter movement, namely X_{rms} Y_{rms} Z_{rms} or the resultant vector. Different values of resistors are placed in series with the meter depending on whether the resultant vector is selected or if the individual coil output is selected. This is because the full-scale output voltage of the rms to dc converter and the full scale output of the vector addition circuit are different.

Power Selector/Battery Charger

This circuit provides an 8 mA current to the internal NiCad batteries to allow for battery charging. The external power is 8V higher than the 7.2 V of the internal batteries. This allows a constant current supply to be made by inserting a 1 KX resistor and diode network between the V_{cc} external and the V_{cc} internal, (8 V/1 KX = 8 mA = required charging rate for batteries). The diode eliminates any possibility of the batteries from discharging if external power supply voltage is less than 7.2V.

This circuit also provides a simple low battery warning, in that V_{cc} must be greater than 4 V for the power on LED to illuminate.

2 Bit Encoded Switch

This switch network provides a binary output depending on its position. The truth table is given below:

Position	Output
1	11
2	10
3	01
4	00

CONCLUSIONS

A probe has been constructed which will find the true rms field levels along each of three orthogonal axes. Further analog processing allows the measurement of a general polarized magnetic field without the need to rotate the probe head as was necessary with a single axis probe. The device is not optimized for accurate measurements of these fields, but is designed to locate current carrying conductors producing the fields.

Further improvements to the device would include converting it to microprocessor operation. This would allow the device to act as a stand alone data logging instrument. It would also allow for features such as autoranging, self calibration and have a wider dynamic range by replacing the analog processing chips.

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